Satellite Characterization of Bio-Optical and Thermal Variability in the Japan/East Sea

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LONG-TERM GOAL

The goal is to understand the physical and optical processes occurring of the Japan/East Sea through the use of satellite thermal and ocean color remote sensing. We have created a climatology of the inherent optical properties (IOP's) using SeaWiFS satellite imagery to define how the bio-optical cycle is driven by the physical processes and circulation.

OBJECTIVES

Our objective is to understand the coupling between the physical processes and the bio-optical processes in the Japan/East Sea basin, and their variability. We describe the surface circulation and how it influences changing bio-optical properties from January 1998 until March of 2000 through the use of satellite sea surface temperature and ocean color. We will examine the monthly variability of bio-optical and thermal properties of water masses to define the major currents of the basin (East Korean Warm Current, Subpolar Front, Tsushima Warm Current, and northern basin waters). We will follow the evolution of the seasonal phytoplankton bloom as it spread throughout the basin and determine how these blooms are influenced of meteorological forcing and sea surface temperature.

We will further determine the basin variability of bio-optical properties (absorption coefficients due to chlorophyll and colored dissolved organic matter (CDOM), and backscattering coefficient) for this two-year cycle using new algorithms applied to SeaWIFS satellite data. These properties will be used to classify water masses in the basin and used to discriminate basin processes. For example, we will differentiate open ocean regions where the phytoplankton absorption dominates the optical signature from coastal regions where a(CDOM) and backscattering control the optical properties. Our research will illustrate the seasonal cycles of biological production and degradation and how they are distributed throughout the basin. We will use bio-optical properties to trace the monthly phytoplankton bloom dynamics from the production through senescence by examining the relationship of the phytoplankton:CDOM ratio.

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14. ABSTRACT

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The circulation of the Japan/East Sea is complex. Warm, oligotrophic water enters the basin from the south through the Tsushima/Korea Strait and bifurcates into the Tsushima Warm Current (TWC) that flows eastward along the northern coast of Japan and the East Korean Warm Current (EKWC) that flows northward along the Korean Peninsula. The EKWC separates from the Korean coast near 37 ° N and meanders eastward, bisecting the basin and forming the Subpolar Front around 40° N. The front separates the cold, dense, weakly-stratified northern water from the warmer, stratified water to the south. The Subpolar Front is a region of very active eddy formation and exhibits strong thermal and bio-optical gradients. We will examine the changing bio-optical properties occurring at the subpolar front and how the surface signature responds to the subduction processes occurring at the front through the annual cycle. We will examine the basin-scale variability of the thermal and bio-optical fields and the small-scale variability along the Subpolar Front by: 1) comparing the location of SST and bio-optical fronts to determine the coupling between the optical and physical signatures, 2) defining the seasonal position and variation of the subpolar front, 3) tracing the bio-optical and SST signature of coastal waters from the EKWC as these waters transition to central basin waters along the Subpolar Front, and 4) assessing surface/subsurface linkages by coupling shipboard and satellite data. These objectives are to characterize and interpret the spatial and temporal variability of SST and chlorophyll in the JES and to establish methods of using satellite observations for optical climatology for navy operations.

APPROACH

SeaWIFS and AVHRR satellite imagery were collected and processed at 1 km spatial resolution from 1998 through March 2000. These data were calibrated, atmospherically corrected, and geo-rectified to a Mercator projection. We applied bio-optical algorithms to derive estimates of the absorption and scattering coefficients and surface chlorophyll. We assembled a time series of SeaWiFS and AVHRR products for the Japan/East Sea to characterize the spatial and temporal variability of the bio-optics and sea surface temperature for the 27-month period. To remove the extensive cloud cover in the region, we assembled monthly mean images for each product. The SeaWIFS processing was performed using a new near-IR atmospheric correction coupled with an in-water semi-analytical model to retrieve the water leaving radiances. This method is an extension of the NASA standard atmospheric correction method, however, it improves accuracy in high scattering waters (coastal and elevated phytoplankton), especially where water radiances at 670 and 765 nm are non-zero. The water leaving radiance in the 6 SeaWiFS channels (412, 443, 490, 510, 555 and 670 nm) were applied to in-water algorithms to discriminate the water's bio-optical properties. These algorithms are 1) Standard NASA – OC4 for chlorophyll and diffuse attenuation k490, 2) Semi-analytical algorithms from NRL (for total absorption and backscattering @443 and 555 nm, respectively) and USF (for total absorption, backscattering and CDOM absorption @ 443, 555 and 412 nm, respectively). We used the monthly mean imagery of these satellite products to classify water masses based on these bio-optical and thermal patterns. Additionally we used the sea surface elevation from satellite altimetry (GEOSAT) to define the physical environment associated with the major currents and eddy structure on a monthly basis.

We examined the differences in surface frontal locations of SST and bio-optical properties by participation in spring/summer (May 1999) and winter (January 2000) SeaSoar cruises aboard the R/V Roger Revelle. We collected real-time satellite imagery to guide the sampling strategy of the SeaSoar program. We also collected surface flow-through optical measurements during the cruise as well as remote sensing reflectance measurements for satellite algorithm development and validation. These

seasonal cruises were aimed at understanding different physical processes in the region: the phytoplankton bloom in the spring and the cold-air outbreaks and subduction events along the Subpolar Front in the winter. We track the location of the subpolar front and link the surface satellite imagery with the subsurface optical and physical environment measured by stations and high resolution SeaSoar data. We also defined four sub-regions in the Japan/East Sea and extracted SST and chlorophyll values from the monthly composite imagery to derive summary statistics to describe the regional variability.

WORK COMPLETED

We completed reprocessing of the AVHRR and SeaWIFS imagery to monthly variability of bio-optical and sea surface products. Over 1000 images were collected from several receive stations in Japan and Korea and from our shipboard receiving system during the two cruises we participated on the R/V Roger Revelle. We have automated the procedures for collection, processing and archiving and have created a web site of the imagery. The reprocessing includes improvements to the atmospheric correction. We have assembled the monthly products and combined them with monthly satellite altimetry and model results of the mixed layer depths. The bio-optical classification has been applied to monthly images and is being coupled to the physical processes from the altimetry and MLD results. We have examined seasonal statistics for bio-optical products in four subregions in the Japan/East Sea basin, and we have examined the variability of the co-location of the thermal and optical fronts. We participated on two SeaSoar cruises and have analyzed the results. In addition to the remote sensing imagery, this includes the shipboard measurements of remote sensing reflectance and flow-though optical data, and integration with the SeaSoar bio-optical (Lee) and station data (Jones).

RESULTS

1. The satellite climatology reveals that the southern basin and northern basin are coupled through the Subpolar Front. There are three arms of warmer waters that extend from the southern Tsushima Current (TC) along the Japan coast into the Subpolar Front. These occur at the western arm (East Korean Warm Current), middle and eastern arm (main flow of the TC) along the Japan coast.

2. The monthly satellite products identified the seasonal cycle of the bio-optical and thermal response of the surface properties within the basin. There are latitudinal differences in the northern, central (Subpolar Front), and southern basin. We observed a spring (April) and a fall (Dec) phytoplankton bloom in the basin. The spring bloom begins in the south and propagates northward reaching a peak in the northern basin. The fall bloom begins in the northern basin and moves southward diminishing in intensity. To examine the regional chlorophyll variability, we divided the JES into four subregions: the Northern Basin, the Subpolar Front, the Southern Basin, and the South Korean Coast. For each region we extracted chlorophyll values from the SeaWiFS monthly composite images and calculated summary statistics and histograms. The spring phytoplankton bloom started in March in the southern basin and progressed northward. At the Korean Coast, South Basin, and Subpolar Front, chlorophyll values peaked in March and decreased through June, with a sharp decrease between April and May in the South Basin. The highest mean chlorophyll concentrations were observed in the South Basin in March. In the North Basin, chlorophyll values remained low through April, peaked briefly in May, and decreased by June; the June values in the North Basin were higher than in the other three regions, however.

3. We established the monthly optical climatology of absorption and scattering for the basin. The optical properties co-vary with the phytoplankton bloom in the central basin. This absorption associated with the chlorophyll concentration is strongly coupled with the seasonal pattern in the central basin, whereas the backscattering coefficient does not show a strong linkage to the bloom. In coastal areas, especially along the Korean coast, and the Wonton basin, elevated absorption and backscattering coefficients occur. Coastal upwelling results from the anticyclonic Korean eddy and exhibits lower temperatures and high absorption and scattering coefficients. These coastal waters are advected by the eddy field at the coast and transported offshore into the region of the Subpolar Front. The offshore transport of coastal waters has not been documented, but the influence of coastal waters on the offshore optical properties is observable as increased absorption and backscattering coefficients within the Subpolar Front.

4. The SST and bio-optical properties from the imagery indicate the circulation patterns.
    a. The East Korean warm current has a seasonal cycle that is identified by the SST and high bio-optical signature. This current separates from the coast and enters the Subpolar Front at different locations.
    b. North of this in the Wonton basin, a strong anticyclonic eddy is observed in both a warm SST and a low bio-optical signature. This eddy is observed from January through June when it loses its surface signature. (models and altimetry with Jacobs and Hogan)
    c. The Subpolar front is identified as a series of eddies on scales of 100 km; these eddies separate the northern from the southern basin. The eddy flow at the Subpolar Front is from west to east and continues throughout the year.

5. We observed a tight coupling between the optical and physical (temperature and salinity) fields. Highest absorption and scattering coefficients were typically coincident with physical gradients. SST at the Subpolar Front increased about 7° C over a 1.5-month period from late April to early June in 1999. During this same period, chlorophyll concentrations at the front decreased sharply. In addition, the elevated chlorophyll values near the Korean coast and in the southern basin also decreased sharply as the phytoplankton bloom that first developed in the southern basin progressed to the front and northward. The SST/chlorophyll relationship is complex and seasonal. Near the Subpolar Front, SST and chlorophyll were positively related in April (i.e., highest chlorophyll values were observed south of the front in warm waters). In May, highest chlorophyll values were located at or just north of the front and in strong mixing regimes (such as areas of convergence and divergence at the edges of meanders). By June SST, highest chlorophyll values were located north of the front in colder waters, and showed an inverse relationship with SST.

6. Cruise data from the summer and winter cruise have been coupled with the surface satellite imagery to understand how the subsurface vertical structure is associated with the surface frontal expression. (coordinated with Lee and Jones). The cruises examined the Subpolar Front and documented the subduction of the cold northern waters into the southern basin, even during the spring period. Temperature and salinity isolines can be displaced 225 m or more in the filaments and eddies along the front, relative to ambient conditions. The vertical structure of the MLD illustrates three layers, which deepen from north to south. The Subpolar Front

characterized by surface eddy is the middle step. The surface signatures do not show these subsurface layers which have elevated chlorophyll and elevated optical properties.

7. The cruise optical data show good agreement with the satellite optical products. Additional data from other participations (Mitchell, Jones) will be used to improve the chlorophyll algorithms.

IMPACT/APPLICATION

Our research documented the seasonal development of the bio-optical and physical surface properties for the Japan/East Sea. We have extended the use of satellite imagery for both real-time and climatological studies of the bio-optical properties and we provide validation for dynamical and biophysical models. The research provides improved concepts for bio-optical research and directs biophysical models of the phytoplankton bloom and how coastal waters interact with the central basin waters. Satellite imagery has been used not only for “tracing the surface circulation” but also for quantitative bio-optical properties. These properties are used to observe the bio-optical processes and monitor long-term changes in this basin. These results will provide improved interpolation of how satellite observations are linked the subsurface and how satellite observations can be better exploited for navy oceanography.

TRANSITIONS

Algorithms being developed for SeaWIFS satellite are being transitioned into the 6.4 SPAWAR Ocean Optical Products. The APS – software developed under this program is used by the used by the Naval Oceanographic Office and the METOC Regional centers. The monthly climatology of the bio-optical properties will be transitioned to the Naval Oceanographic Office- N3-Data Warehouse and will be used with the Organic MCM FNC. The optical properties has direct impact of the performance of Laser imaging and camera system used in MCM and Special operations.

RELATED PROJECTS

1. – NRL 6.1 - Hyperspectral Character of the Coastal Zone

2. – NRL 6.2 Nesting of satellite ocean color products at large and fine scales

3. –ONR 6.1 – 6.2 - HYCODE - hyperspectral ocean color satellite NEMO.

4. - ONR- 6.3 MCM- Environmental Support to the optical environment – FBE- Kernel Blitz and Hotel

5. - SPAWAR- 6.4 – Ocean Optical Products

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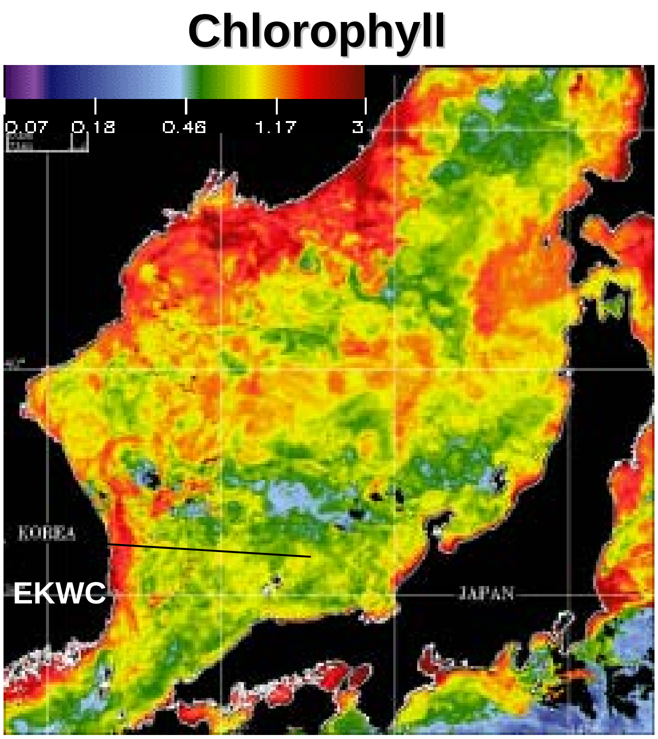

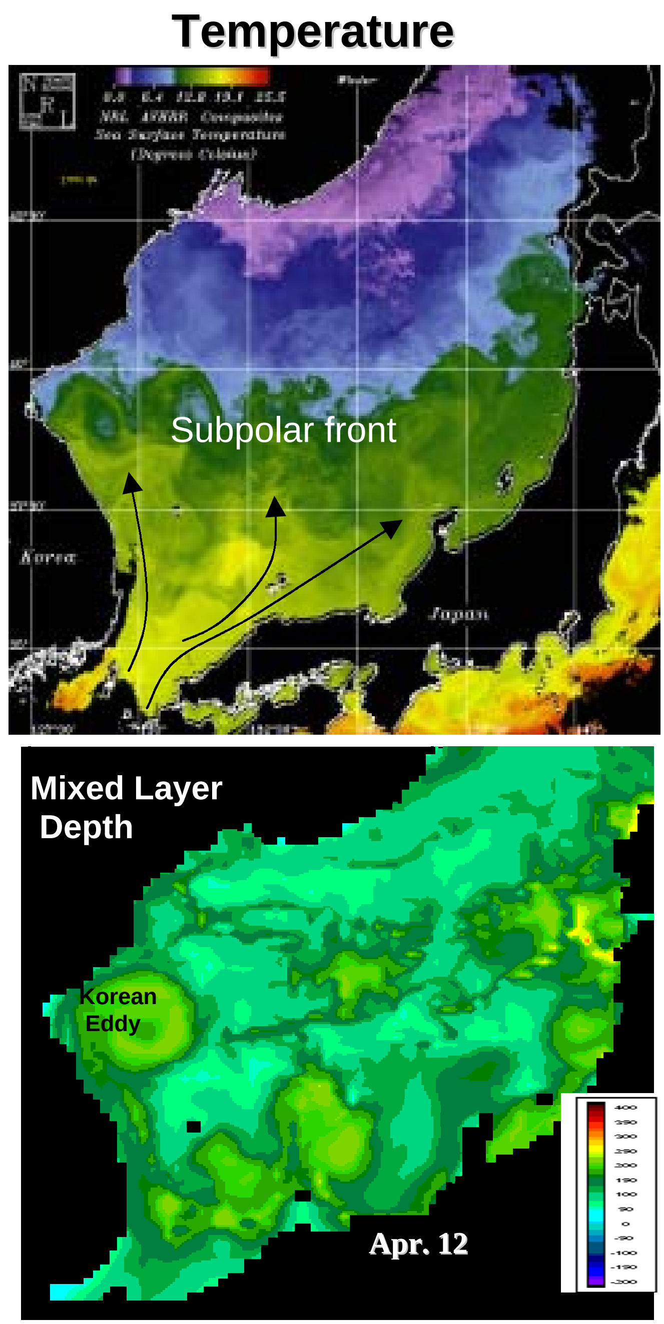

Figure 1: The phytoplankton bloom of April 1999. The monthly composites show the coupling of the physical and biological processes. Note location of transect used in figure 3 .

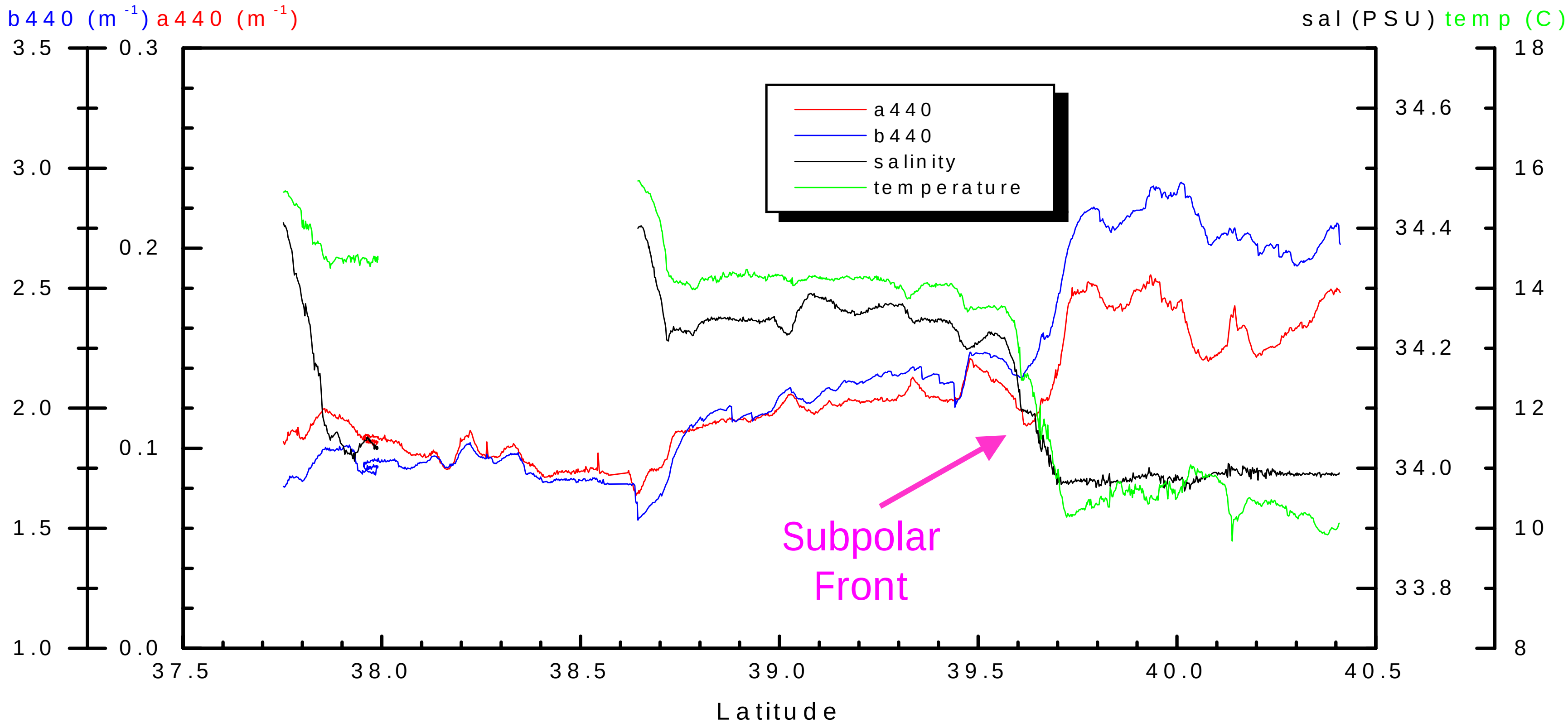

Figure 2- Shipboard Flow-Though data illustrates physical vs. optical properties across the subpolar front (N-S transect). The optical and physical fields are tightly coupled.

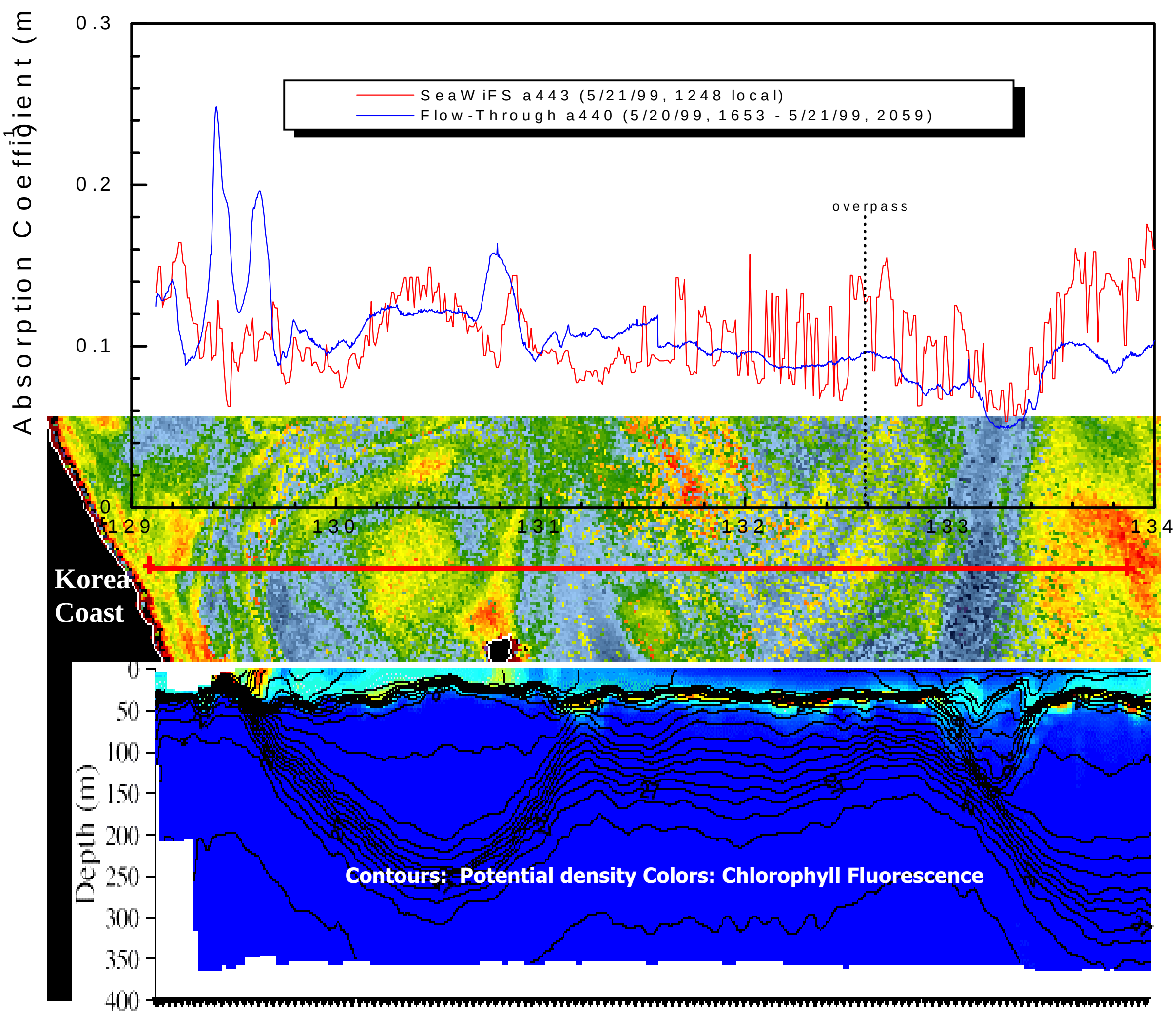

Figure 3 –SeaWIFS bio-optical and Shipboard Measurements: across a Eddy in off the EKWC - Surface and Subsurface Coupling